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Forecasting Research Division
Technical Report No. 90

Moisture spinup - a possible solution

by

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August 1994

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1. Introduction

One aspect of current concern is the apparent lack of precipitation and cloud in the early stages (0-12 hours) of LAM forecasts, relative to the later forecast periods. This adjustment during the early stages of a forecast is often called a 'spin-up'. It has been a characteristic of most data assimilation systems for many years and is usually the result of suppressed dynamical activity due to the initialisation process. We have no reason to suspect such a problem in the Met. Office system (Lorenc et. al. 1991) since there is no explicit initialisation step. However, it is becoming clear that some feature of the assimilation process or the observational data which is assimilated is responsible for this moisture deficiency. In a global context, the same problem is less important since that forecast period is of less value, but it is a possible contributor to another problem. When the soil moisture is allowed to evolve freely during an extended global data assimilation cycle, there is a marked drying out of the model soil surface. This is an unacceptable feature since it impacts adversely on convection and surface temperature forecasts over land, thus at present within the operational system, the soil moisture field is reset regularly to a climatological value.

In this paper, I give several illustrations of the problem in section 2. Then focus on the assimilation process and observing system in section 3, where a series of experiments are run to shed light on the problem and point towards possible solutions. These experiments are global sensitivity experiments since the operational LAM assimilation period is too short to see the full impact of alternative processing. A LAM case study is given in section 4 using the 'best' option arrived at during the global studies discussed in the earlier section. The conclusions are drawn together in section 5.

2. The problem

Figures 1(a-b) illustrates the differences in LAM cloud amounts at T+0 and T+12 respectively. These figures show monthly mean low cloud coverage for April 1994 (expressed as a percentage with shading in excess of 30%[the bold contour near the UK] and a contour interval of 20%) . It should be noted that the only observing system which directly impacts on the moisture field is the radiosonde network. Thus over the oceans the moisture field is largely controlled by the model evolution and we should not expect significant differences between T+0 and T+ 12 means. The major differences between these two figures is over the UK where the 30% contour has encroached in the period between T+0 and T+12.

Figures 2(a-d) illustrates the LAM moisture increase in terms of rainfall totals. In this case we have total accumulations for January 1993. With the MORECS estimate (based on observations) at figure 2a, and the forecast totals for periods T+0 T+12, T+12 T+24, T+24 T+36 at figures 2(b-d) respectively (each forecast total being the sum of all 00GMT and 12GMT runs). The deficiency in rainfall in the early forecast period is clear, when one looks for instance at the 75mm and 100mm bold contours together with the peak values over the western hills. The best match with observations seems to the T+12 T+24 period which is intermediate between a dry first period and a wet last period.

The third measure of diagnostic information is based on the radiosonde RH observation

differences from model fields. Figure 3 gives this difference as a function of forecast range (for all UK radiosondes during March 1994) at three levels. What we see, is the model having a positive bias with respect to the observations at all forecast ranges including T+0, but a large increase in the bias between T+0 and T+12. If we believed the observations of RH then the model needs to be wetter than it should before it generates the correct rainfall amounts according to the rainfall validation in the previous figure.

More detailed diagnostics of model fit to observations are available from the data assimilation system. Within the Observation Processing Database (OPD) we have observation differences from analyses (o-a) and from T+6 background (o-b) for each observation. Barker (1994) has studied these and noted a synoptic dependence to the differences of both temperature and relative humidity. He further noted that the relative humidity difference is only partly accounted for by the temperature difference. The change in relative humidity due to temperature observations correcting a model temperature bias is something we investigate further in the next section. Figures 4(a-b) illustrates typical OPD differences. They show the (o-a) and (o-b) values of temperature and relative humidity respectively for European radiosondes during September 1993. Note that the (o-b) has a larger negative value than (o-a) implying that the mean analysis RH values are more faithfully reflecting the observations and are lower (drier) than the forecast.

Maycock and Macpherson (1994) note that generating cloud via the UM cloud scheme given a sonde RH profile does not yield the same cloud as the collocated synop report. They find a bias of near 3 octas using several months of UK radiosonde data. Of course this may point to a problem with the UM cloud scheme. In fact Campana et al (1994) has developed a RH to cloud algorithm for the NMC model using observational data, which, unlike the Unified Model, estimates some cloud at very low RH. However, they appear to have ignored any possible problems with the observations and also seem to have not taken convective cloud into account.

From a data assimilation viewpoint there is not much we can do with the cloud scheme (if indeed it is wrong). An expedient massaging of the observations seems a more straightforward approach to the problem as this more satisfactorily resolves the contradictory nature of the evidence. Fortunately there is a body of independent evidence to suspect that radiosonde RH observations have problems, and therefore such massaging would not be unreasonable. Apparently the calibration of the sensors on many radiosondes is unreliable near saturation, it being based on an extrapolation from the 0-80% RH regime where calibration is performed. A 3% bias in Vaisalla radiosondes has been reported (Nash, personal correspondence). McKenna (1994) has provided evidence to confirm this by examining collocated radiosonde and MRF flight data. Wade and Schwartz (1993) have produced similar evidence of a problem with US sondes.

Aside from possible measurement problems, we have a representivity problem. In our system, we vertically average the observed data to provide the assimilation with data which is representative of the model layers (Ingleby and Parrett, 1994). Thin saturated layers are not represented in these assimilated profiles; and it might be desirable for some purposes to retain such observed cloud in the models albeit at a greater thickness than is actually observed.

3. Global experiments

Global sensitivity experiments were run since the operational LAM assimilation period is too short to see the full impact of alternative processing. The basic experiment consisted of a 3 day global data assimilation followed by a forecast. Diagnostic information from the control experiment confirmed that the case chosen exhibits the sort of problems noted in the monthly mean verification data presented in the previous section. We display this diagnostic information in figures 5(a-d) in the form of timeseries of globally averaged precipitation and high, medium, low cloud respectively. Note the 12 hour periodicity during the assimilation cycle with reductions coinciding with the introduction of radiosonde relative humidity data in the period running up to the main synoptic hours. Note also the mean level of both precipitation and total cloud during the assimilation cycle (1-432 timesteps) is significantly less than in the forecast. For precipitation, the assimilation value is 0.26e-4 increasing to a forecast value of 0.32e-4 (in SI units; which in mm/day is 2.2 increasing to 2.8); the latter value being more in accord with climatological expectation. For total cloud cover, the assimilation value is 43% increasing to a forecast value of 51%. Even the latter value is on the low side compared with climatological estimates of near 60% (eg from ISCCP, Rossow et al 1993)

3.1 No RH Obs

The first experiment was to run without any RH observations. The precipitation and total cloud cover timeseries for this run (superimposed on the control) is given in figures 6(a-b). We see the periodicity has been much reduced and the level of the precipitation during the assimilation has been increased to about 0.29e-4, which is still significantly down on the forecast value. Given the 'improvement' in the statistics, we might be tempted to say that since the RH field is largely governed by the model dynamics, we can let it evolve without using RH observations. Figures 7(a-c) and 8(a-c) illustrate the 700hPa RH fields at T+0 and T+24 (together with difference fields) obtained from these runs with and without RH observations. The validation of these runs (fit to RH obs) is given in Table 1.

Verification Area	Experiment	T+0	T+24
Northern Hem (90-30N)	Control	9.0	20.5
" "	No RH obs	19.4	21.3
Tropics (30-30)	Control	8.7	18.4
"	No RH obs	21.3	21.7

Table 1. Comparative fit to RH obs of runs with and without RH obs

We see substantial differences in the RH fields from these two experiments , particularly at T+0 but even at T+24. The validation shows a substantial impact at T+0, but only a marginal impact at T+24 (more so in the tropics where dynamic forcing is weaker). This suggests that at least in this 0-24 hour timescale the RH observations are likely to be important (although with a degree of importance diminishing with time) if the bias problem

can be addressed.

3.2 Boosting radiosonde RH

The second experiment made use of RH observations but incorporated a scaling to boost the observation values near saturation. Barker (1994) suggested a parabolic boost to the observations and this was tested in the second experiment. The boost was only applied where the original layer mean observation (RH_{ob}) exceeded 80% (RH_{crit}). The precise formula is given in equation 1.

$$\Delta RH = \alpha(100\text{-}RH_{ob})(RH_{ob}\text{-}RH_{crit}) \quad \text{for } RH_{ob} > RH_{crit} \qquad (1)$$

where α should not exceed $(100\text{-}RH_{crit})^{-1}$ and was in fact set to that maximum value

Figures 9(a-b) show the timeseries comparison for this run. Here we see that both figures 6 and 9 are rather similar for precipitation (both about 0.29e-4 during the assimilation period), indicating that the observations can be assimilated without the adverse impact with an appropriate boost near saturation. There is less impact on the cloud diagnostics in this experiment than the first.

Ingleby and Maycock (private communications) have examined alternative strategies to vertical averaging and suggested that a simple interpolation to mid-point of layer together with a somewhat smaller boost is more appropriate. They have determined that on top of the midpoint interpolation, a boost of which takes the form of a piece-wise linear function (equation 2) will give a cloud 'observation' (based on the model cloud scheme) which matches the surface reported observation.

$$\begin{aligned}
\Delta RH &= 0 && \text{for } RH_{ob} < RH_{crit} \\
\Delta RH &= (RH_{ob}\text{-}RH_{crit})/(90\text{-}RH_{crit})*4.6\% && \text{for } RH_{crit} < RH_{ob} < 90 \\
\Delta RH &= 4.6\% && \text{for } 90 < RH_{ob} < 95 \\
\Delta RH &= (100\text{-}RH_{ob})/(100\text{-}95)*4.6\% && \text{for } 95 < RH_{ob} < 100 \\
\Delta RH &= 0 && \text{for } RH_{ob} = 100
\end{aligned} \qquad (2)$$

Figures 10(a-c) illustrate the difference between layer average and midpoint interpolation as well as showing the impact of a 'boost'. (The same model background is shown on all these plots and should be ignored, concentrate only on the observation plots [identified with a * at the lower part of the ascent] as reported ['the obs levels'} and as processed for assimilation ['the model levels']). In 10a, the layer averaged profile, the alternate moist and dry slots observed and not as exaggerated in the processed profile. In 10b, there is a closer match, but the upper two 'cloudy' layers have RH values which would not translate into a significant cloud fraction. 10c is better in this respect. This alternative boost strategy has yet to be tested in assimilations, but there is no reason to suspect that it will provide significantly different results, although it is preferable to the parabolic boost function in that it is based on real data.

3.3 Conserving RH during temperature assimilation

After adjusting the radiosonde reports, we are still left with a deficiency in rainfall during the assimilation cycle. The next experiment identified the contribution to this deficiency due to temperature reports. We note that the model has a cold bias and the temperature observations dry as they warm because mixing ratio is preserved during the temperature assimilation. We have addressed the problem in the third experiment by preserving relative humidity during the temperature assimilation. Figures 11(a-b) shows the timeseries from this run to be compared with figures 6 and 9 of earlier runs. Note the increased level of precipitation. The results from this experiment differ in respect of cloud, where a substantial increase is evident. This is because we are changing points where the humidity was previously far from saturated, and also the change has a more global character, not being restricted to the radiosonde locations. The periodicity is still present since we have done nothing in this run to change the assimilation of radiosonde RH observations.

3.4 The 'best' option

The fourth experiment includes both the changes tested in experiments 2 and 3. The timeseries in Figure 12(a-b) give precipitation and total cloud cover comparisons (similar to figures 6, 9 and 11). After an initial adjustment during the first 24 hours of the assimilation, the average values settle down to a level which is comparable to that obtained in the first couple of days of the forecast. Figure 13(a-c) show the high, medium and low cloud comparisons. Although the spin-up during day 1 of the forecast has been removed (timestep 432-576), there still seems to be an upward trend to the high and to a lesser extent medium cloud later in the forecast which might possibly be a pointer to a model bias problem.

The figures 14 and 15 show the global rainfall fields (6 hour totals t-6 to t+0) from the control and fourth experiment. At first glance these appear to be similar, but on closer inspection (with the aid of a difference chart), there are numerous differences both increases and decreases. The reader is invite to look!

The by-product of this increased precipitation during the assimilation is a lessening of the dry land surface drying in the model. Figure 16 shows the difference in soil moisture over western Europe during the experiment. This reproduction of a colour plot does not look to convincing, but reassured that all four of the darker areas (Spain, Holland, Sweden and Finland) imply trial moister) Globally, the drying reduced from 0.5% per day to 0.1% per day.

4. A LAM Case Study

Four LAM cases were run over a period 22-25 Feb 1994. These experiments all started from operational global analyses and used operational boundary information (with the dry bias), so the adjustment period for the revised moisture processing was only 12 hours. A significant impact was noted in the forecast rain and cloud maps in the first 12 hours on several of these cases. Beyond 12 hours, the impact tended to diminish and was not deemed significant. With the LAM, the T+6 fields may not be especially useful as a forecast, but it is still extremely

important that they are as accurate as possible since deficiencies in the early stages of the forecast reduce forecaster confidence in the product.

Results from one of these cases is illustrated in figures 17(a-b)which show rainfall forecasts from the test and control runs for 24th Feb. The radar validation in Figure 18 clearly points to the test run being more realistic in three distinct areas (circled in 17a). The rain over the southwest associated with the low is correctly further north and heavier in the test. The same applies to the band of rain/snow over south-central Scotland. The showers to the West of the Shetlands are almost absent in the control.

5. Conclusions

Problems have been identified with adjustment of the RH field during the assimilation and in particular with the processing of radiosonde RH data, which appears to be biased low near saturation. Corrective action for these deficiencies has resulted in an assimilation system from which spin-up is largely absent. Within the global system, this might have a significant advantage. The moisture analyses can be used as a starting point for climate studies. Also there is evidence that the soil moisture might be able to evolve freely in the model, without resulting in unacceptable drying. Within the LAM system, a clear improvement in 0-12 hour forecasts has been noted in cases where the initial precipitation and cloud fields are deficient.

Acknowledgements

Thanks to Frank Saunders (CF) for providing the operational validation examples, and to Dale Barker, Bruce Ingleby, Adam Maycock and Bruce Macpherson (FR) for contributing to the debate on the radiosonde moisture bias problem.

Figures

Figure 1 Monthly mean low cloud amounts T+0 and T+24 : April 94.

Figure 2 (a)MORECS and LAM precipitation accumulations (b)0-12, (c)12-24 and (d)24-36 : Jan 93.

Figure 3 Timeseries RH (model-ob) at 3 levels : Mar 94

Figure 4 OPD mean (o-a),(o-b) for (a)temperature and (b) RH; Europe sondes, Sept 93.

Figure 5 Timeseries of (a)precipitation plus (b)high, (c)medium & (d)low cloud global means for control run from Oct 93 case.

Figure 6 Timeseries of (a)precipitation and (b)total cloud global means for 'no RH obs' case and control from Oct 93 case.

Figure 7 RH field at t+0 (a)with and (b)without RH obs and (c)diff from Oct 93 case.

Figure 8 RH field at t+24 (a)with and (b)without RH obs and (c)diff from Oct 93 case.

Figure 9 Timeseries of (a)precipitation and (b)total cloud global means for 'sonde boost' case and control from Oct 93 case.

Figure 10 Profiles of RH from model background and observations on obs levels and model levels for station 01415 on 12/1/94. Plot are (a) layer averaged, (b) interpolate to midpoint and (c) interpolate plus boost.

Figure 11 Timeseries of (a)precipitation and (b)total cloud global means for 'no RH change during T assimilation' case and control from Oct 93 case.

Figure 12 Timeseries of (a)precipitation and (b)total cloud global means for 'final trial' case and control from Oct 93 case.

Figure 13 Timeseries of (a)high, (b)medium and (c)low cloud global means (trial version and control) from Oct 93 case.

Figure 14 6 hour global precipitation accumulation (6-12z 11/10/93) from control run.

Figure 15 6 hour global precipitation accumulation (6-12z 11/10/93) from trial run.

Figure 16 Soil moisture differences (control-trial) after 2 days assimilation: Oct 93 case

Figure 17 LAM T+6 forecast precipitation (a)trial and (b)control for 24th Feb 1994

Figure 18 Radar verification for 24th Feb 1994 forecasts.

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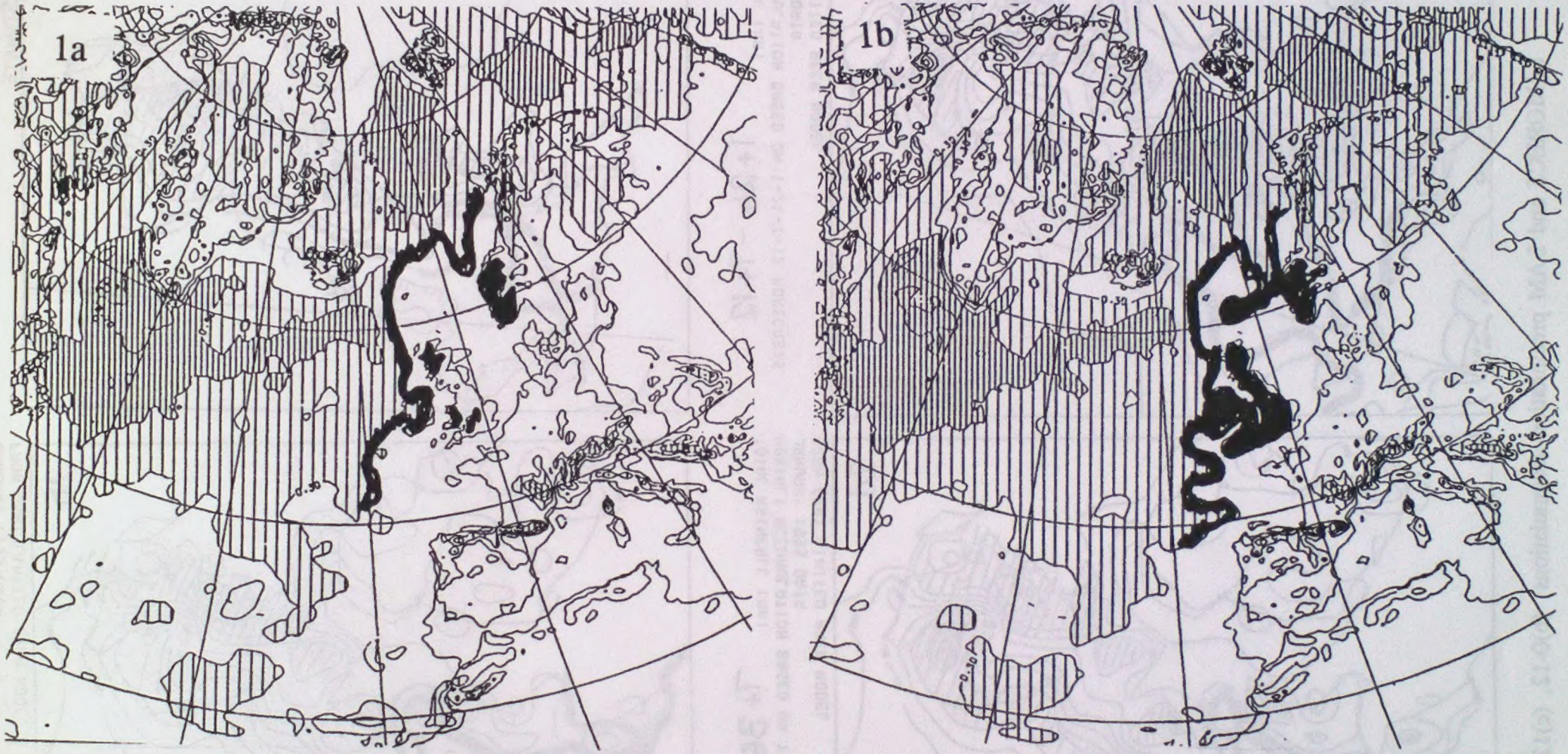


Figure 1 Monthly mean low cloud amounts T+0 and T+24 : April 94.

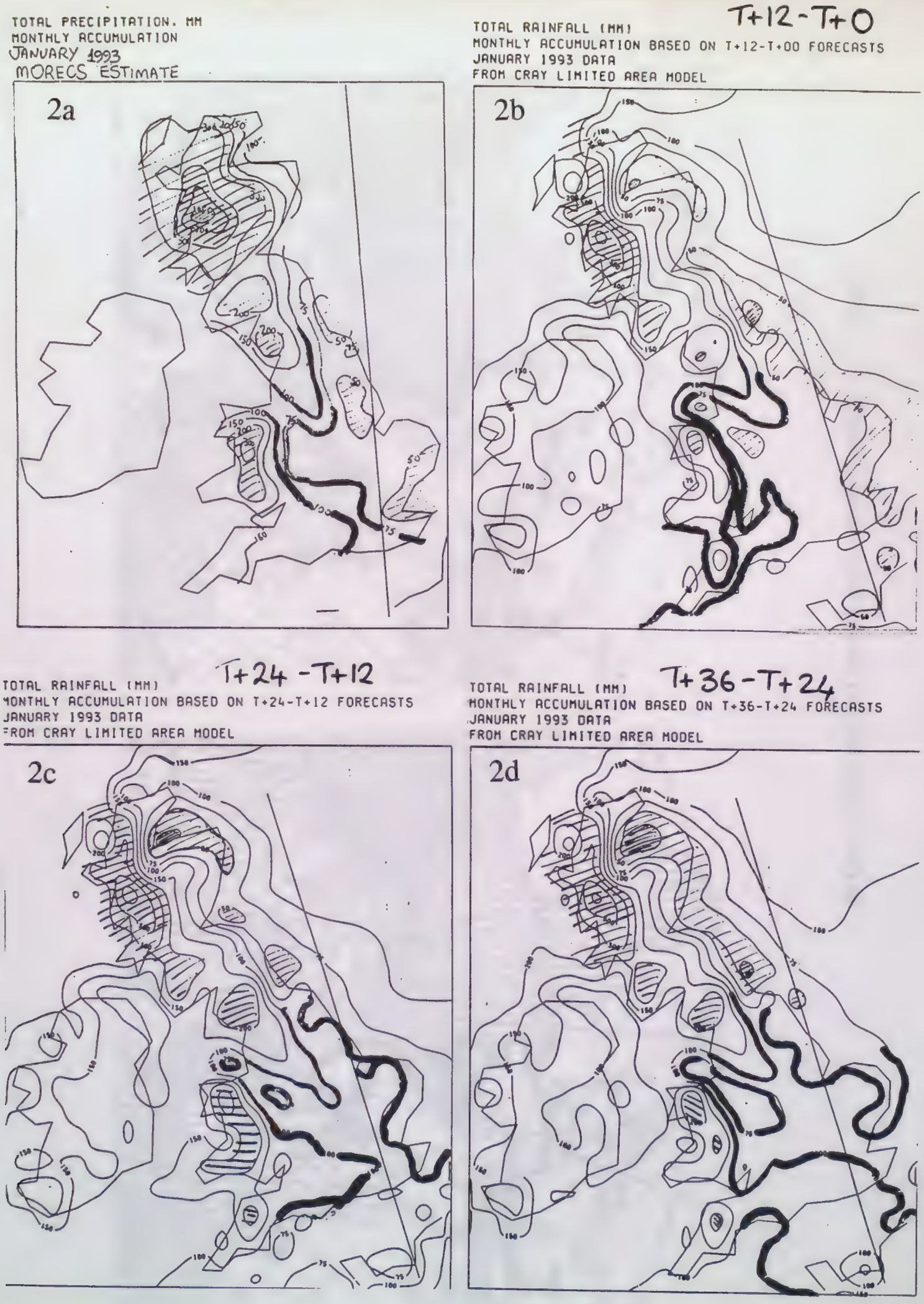


Figure 2 (a)MORECS and LAM precipitation accumulations (b)0-12, (c)12-24 and (d)24-36 : Jan 93.

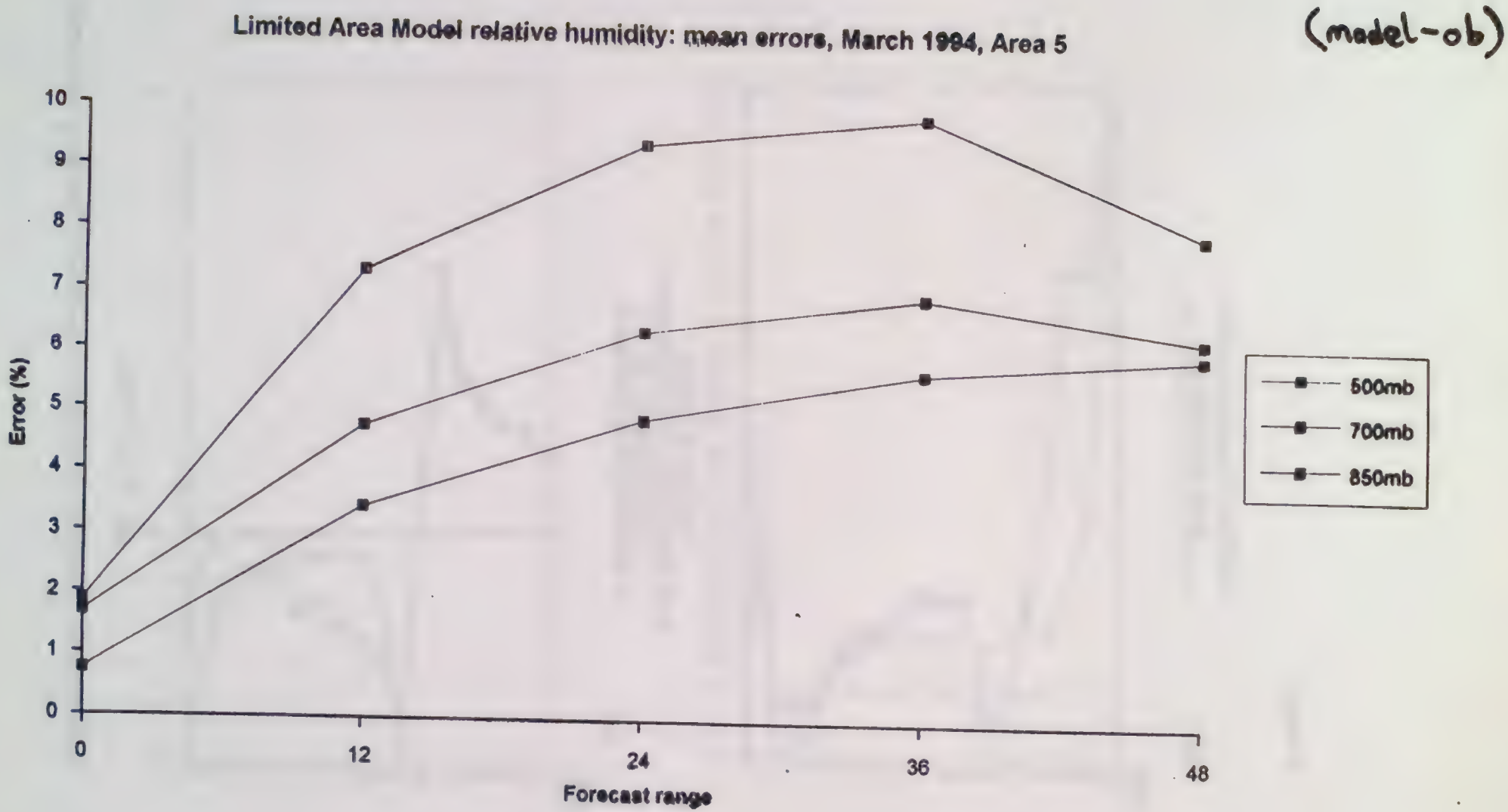
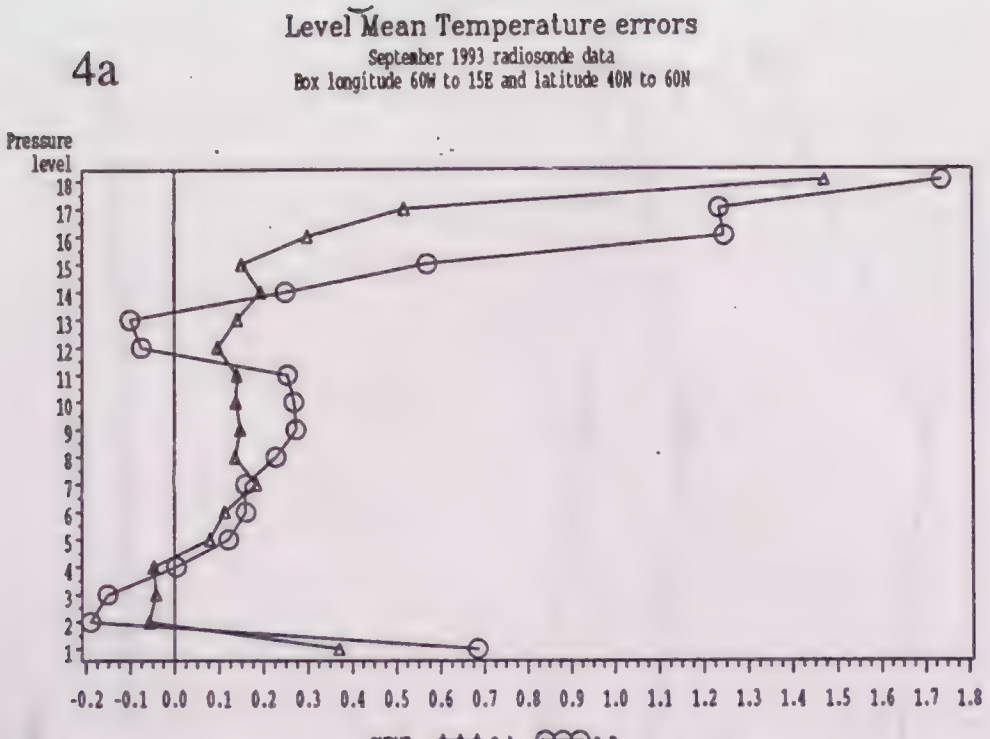


Figure 3 Timeseries RH (model-ob) at 3 levels : Mar 94

Europe.

4a



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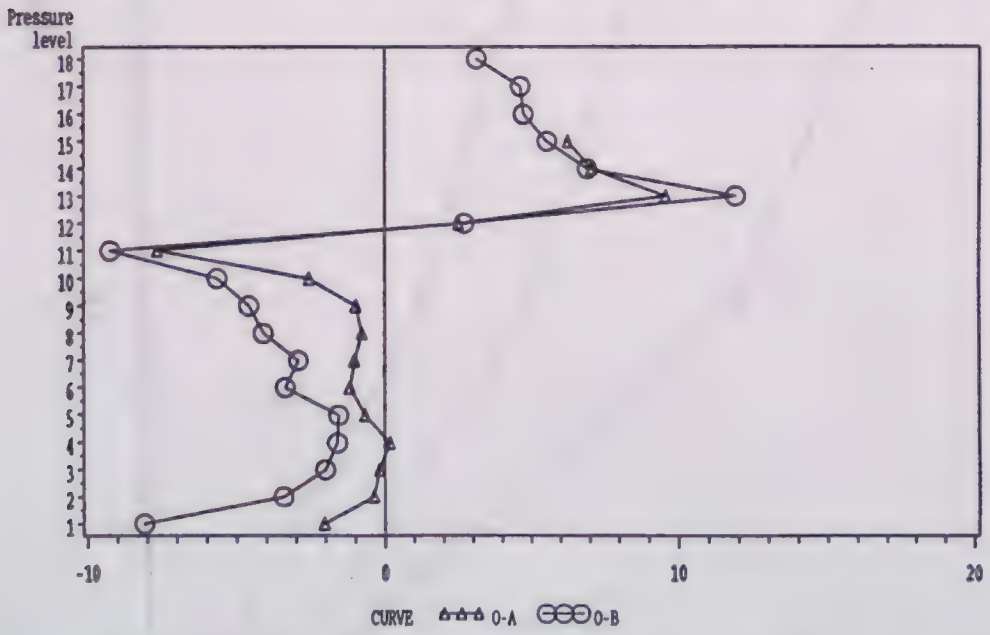


Figure 4 OPD mean (o-a),(o-b) for (a)temperature and (b) RH; Europe sondes, Sept 93.

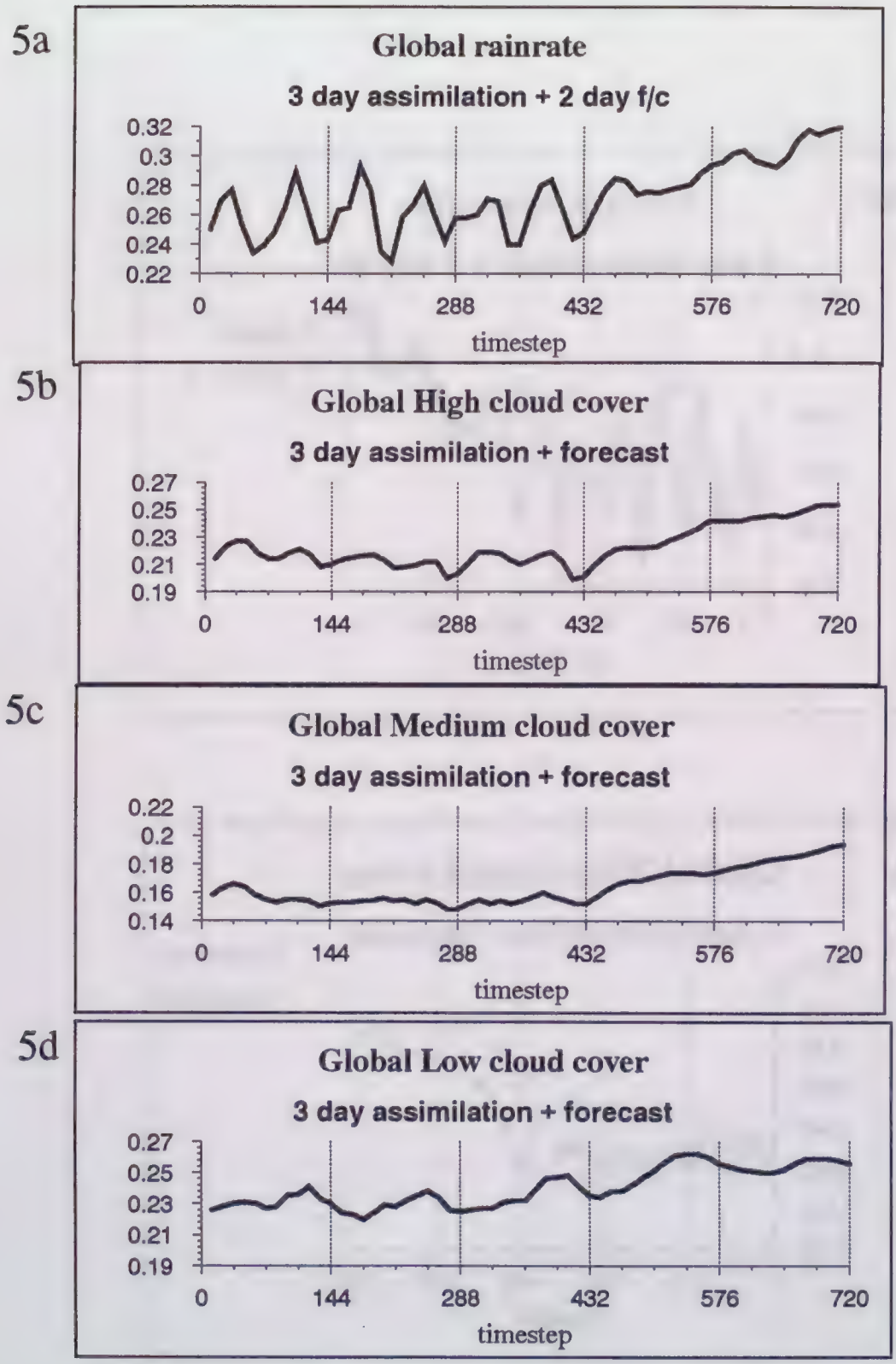
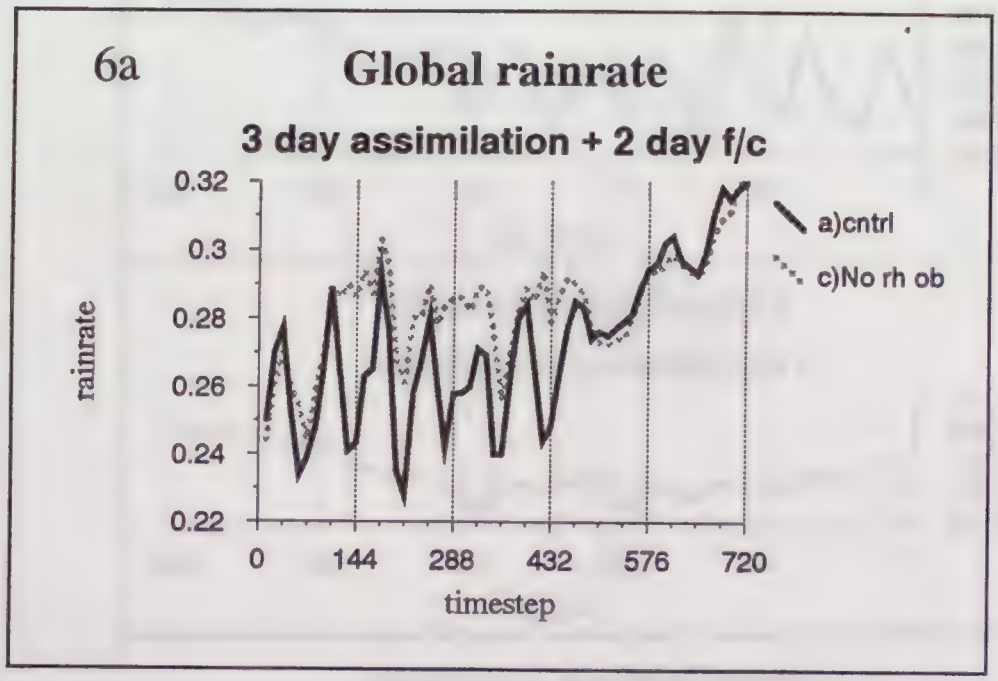


Figure 5 Timeseries of (a)precipitation plus (b)high, (c)medium & (d)low cloud global means for control run from Oct 93 case.



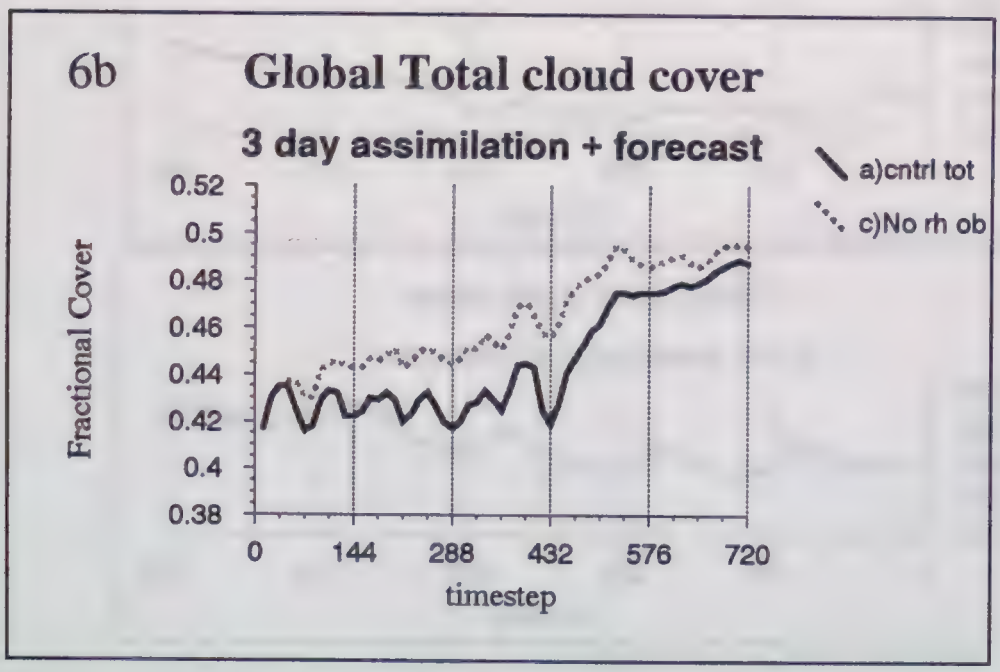
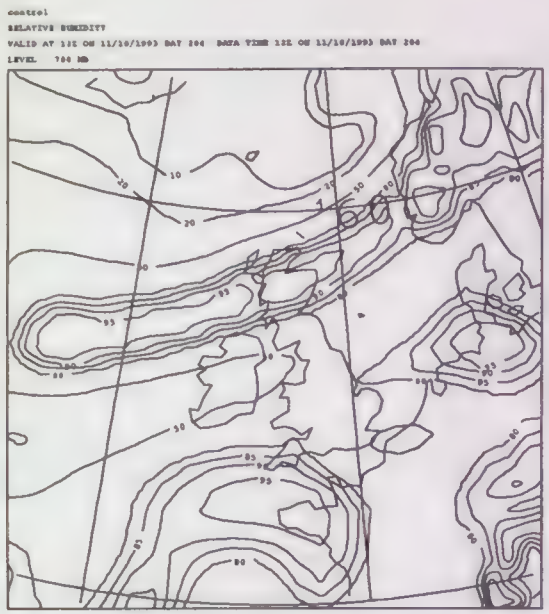


Figure 6 Timeseries of (a)precipitation and (b)total cloud global means for 'no RH obs' case and control from Oct 93 case.

7a



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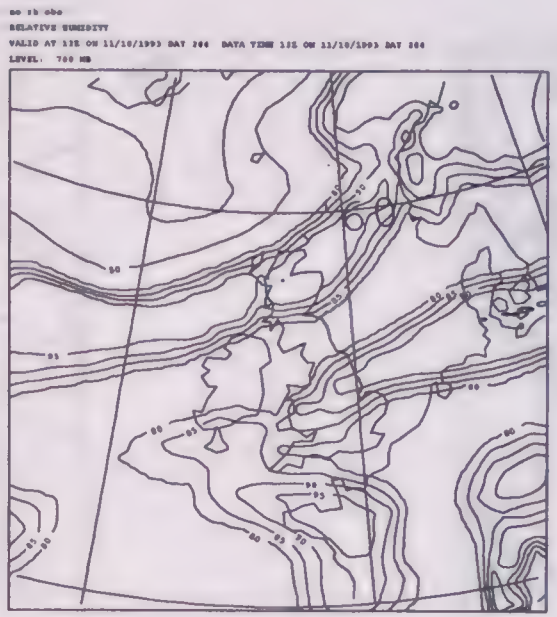

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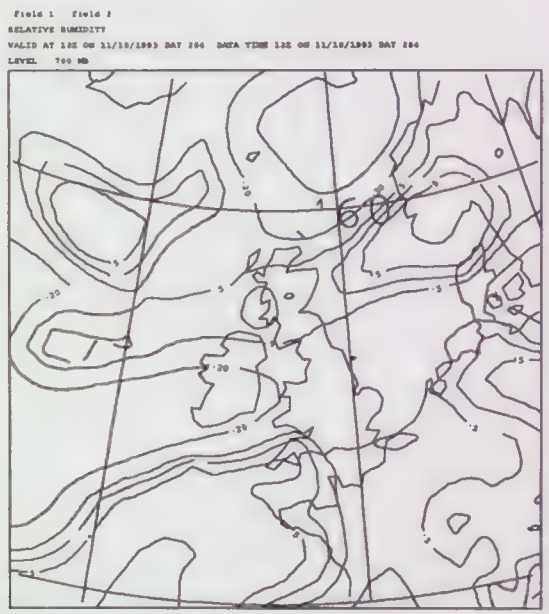

Figure 7 RH field at t+0 (a)with and (b)without RH obs and (c)diff from Oct 93 case.

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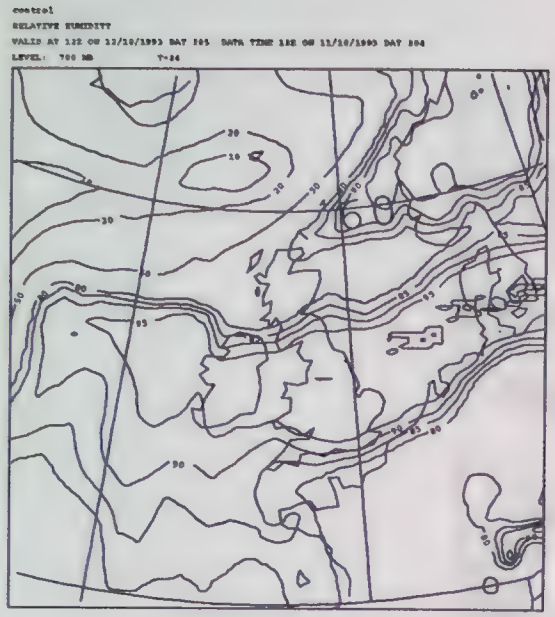

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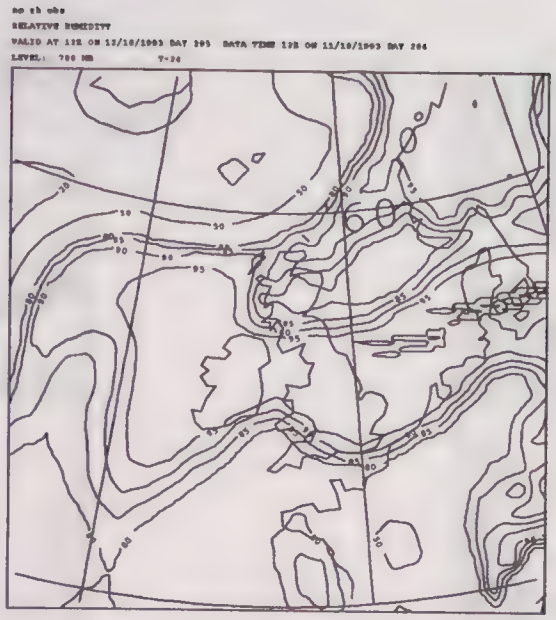

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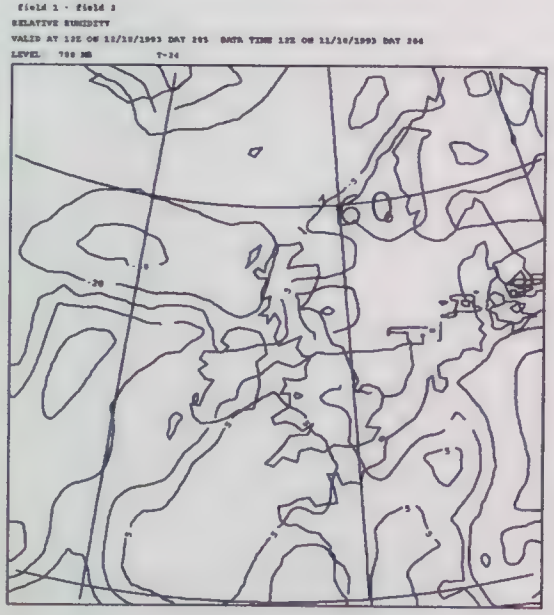
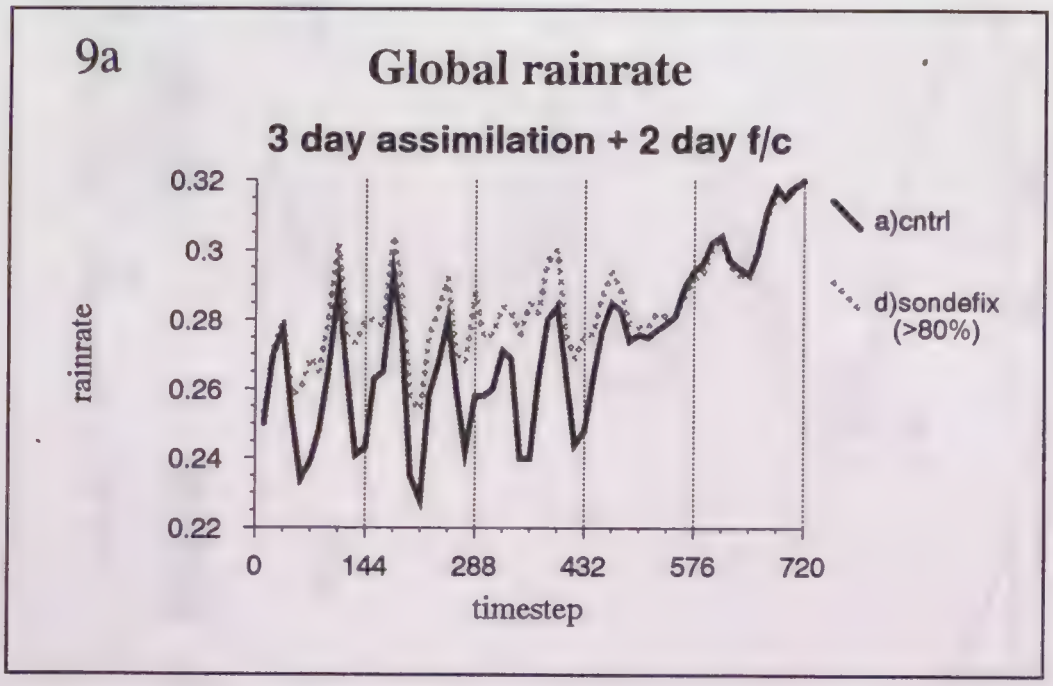
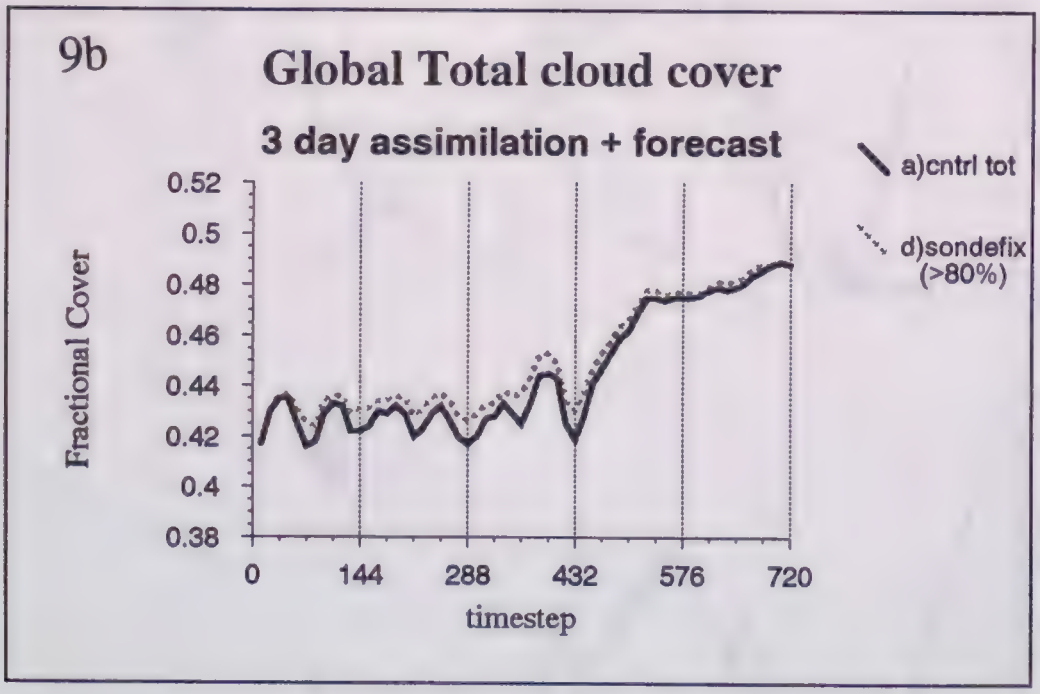


Figure 8 RH field at t+24 (a)with and (b)without RH obs and (c)diff from Oct 93 case.





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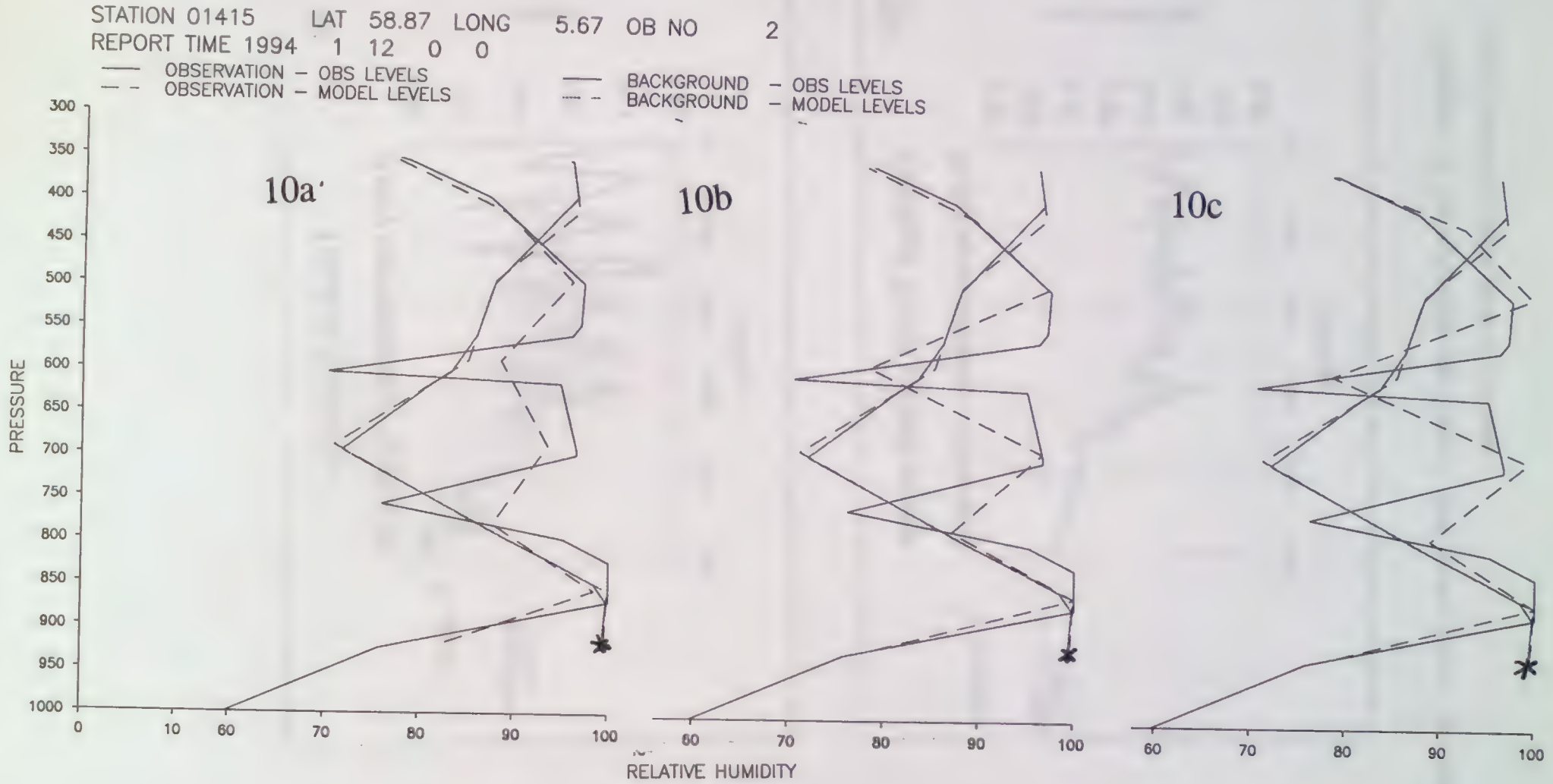

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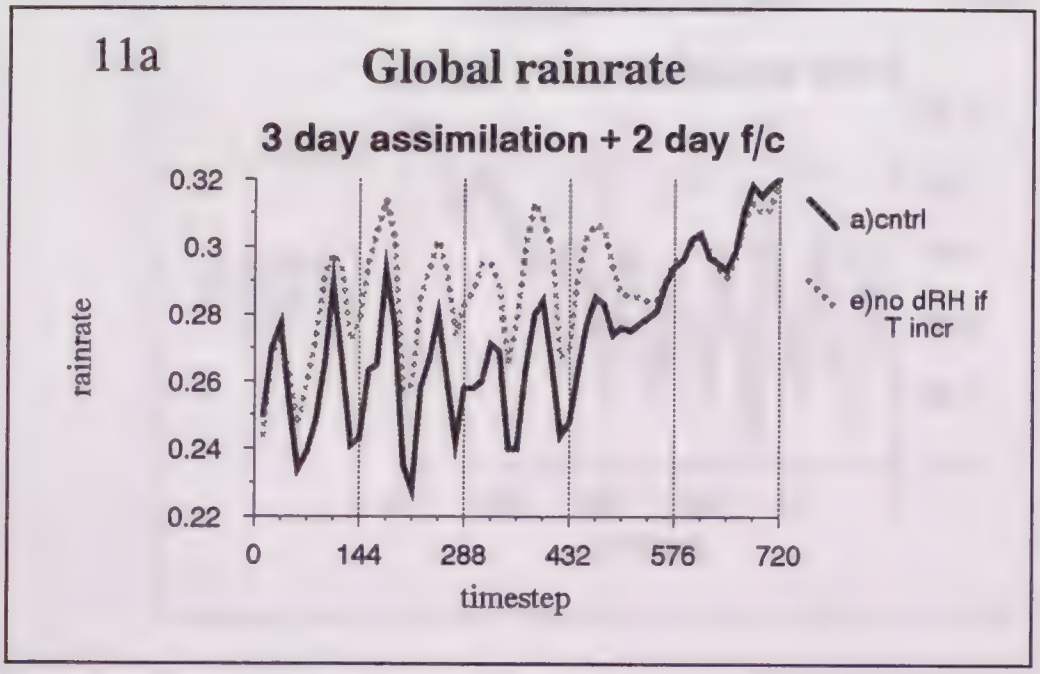


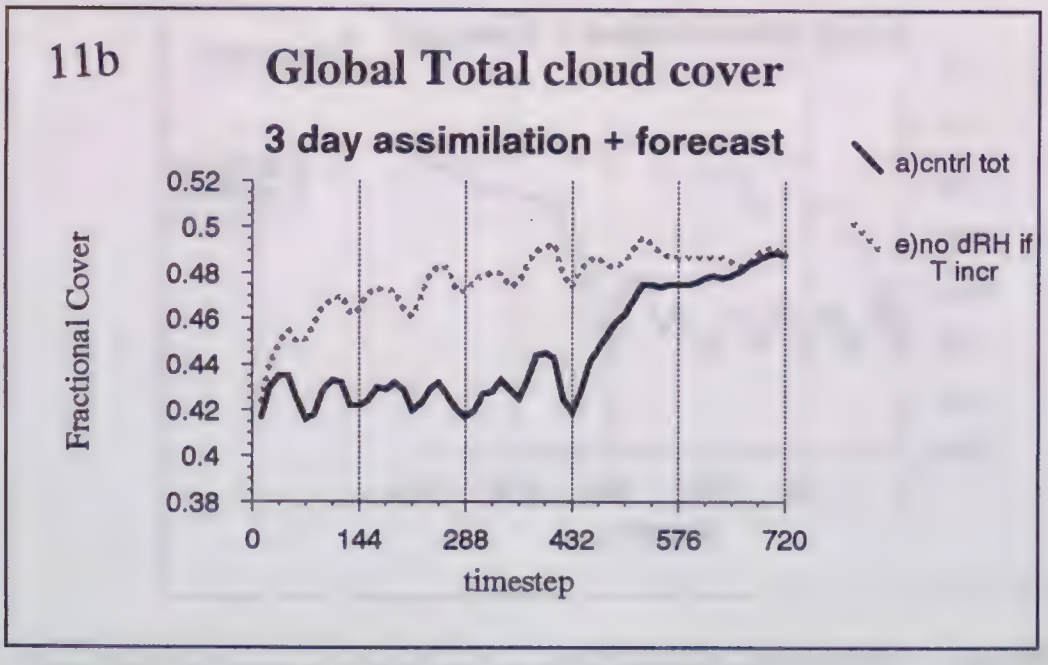
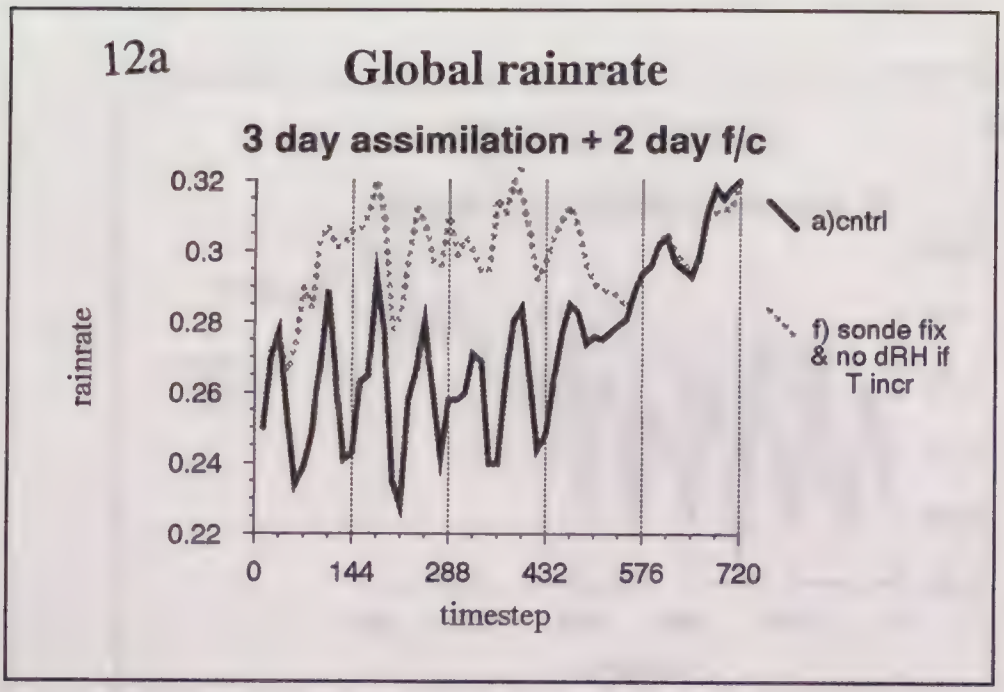


Figure 11 Timeseries of (a)precipitation and (b)total cloud global means for 'no RH change during T assimilation' case and control from Oct 93 case.



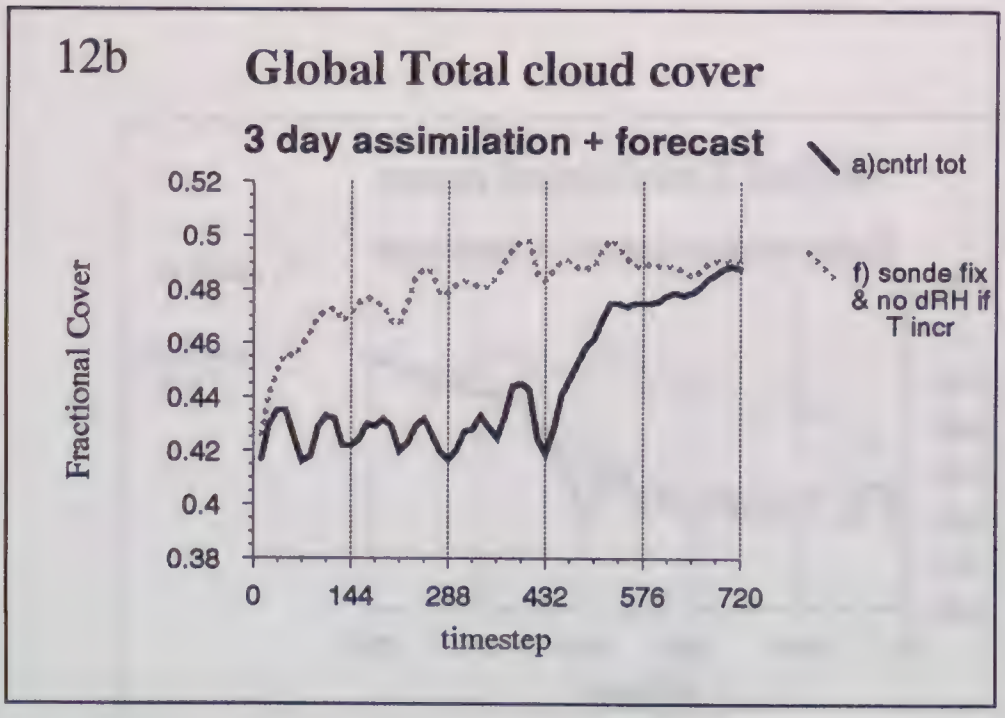
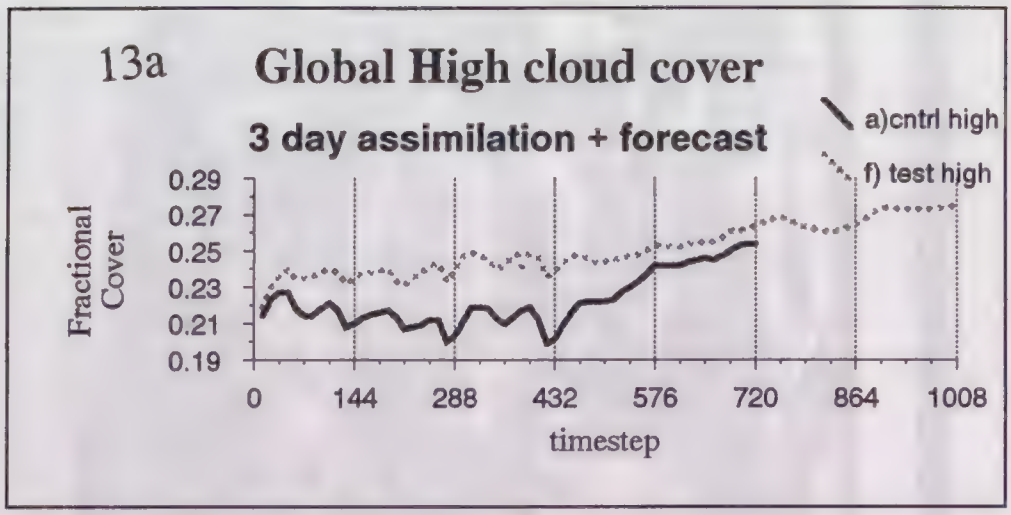
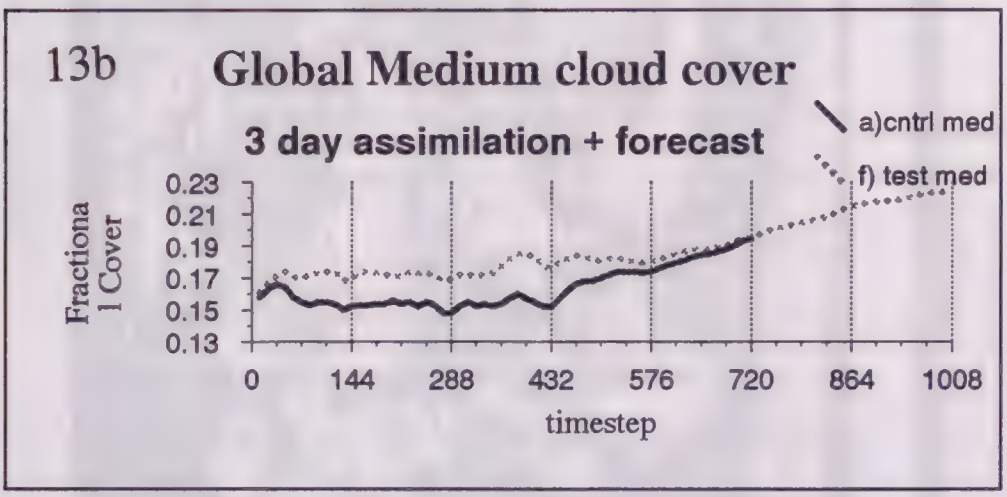


Figure 12 Timeseries of (a)precipitation and (b)total cloud global means for 'final trial' case and control from Oct 93 case.





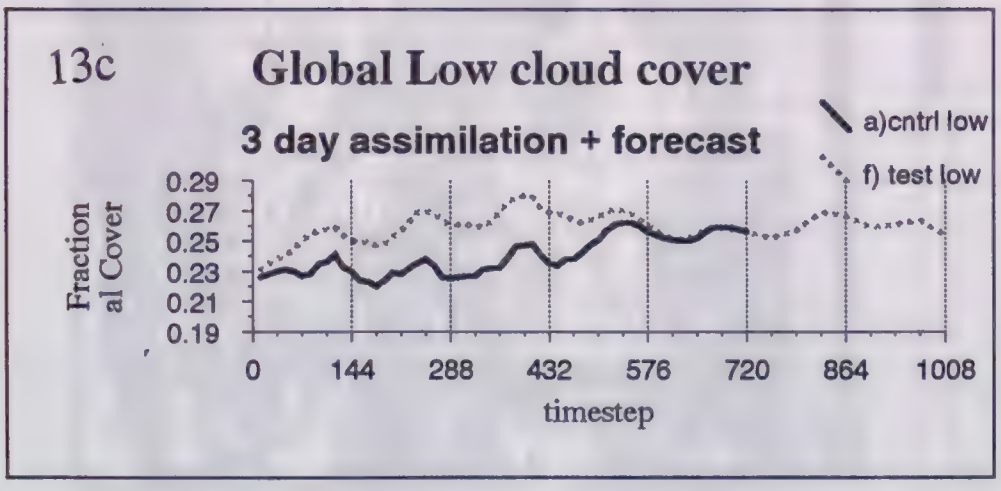


Figure 13 Timeseries of (a)high, (b)medium and (c)low cloud global means (trial version and control) from Oct 93 case.

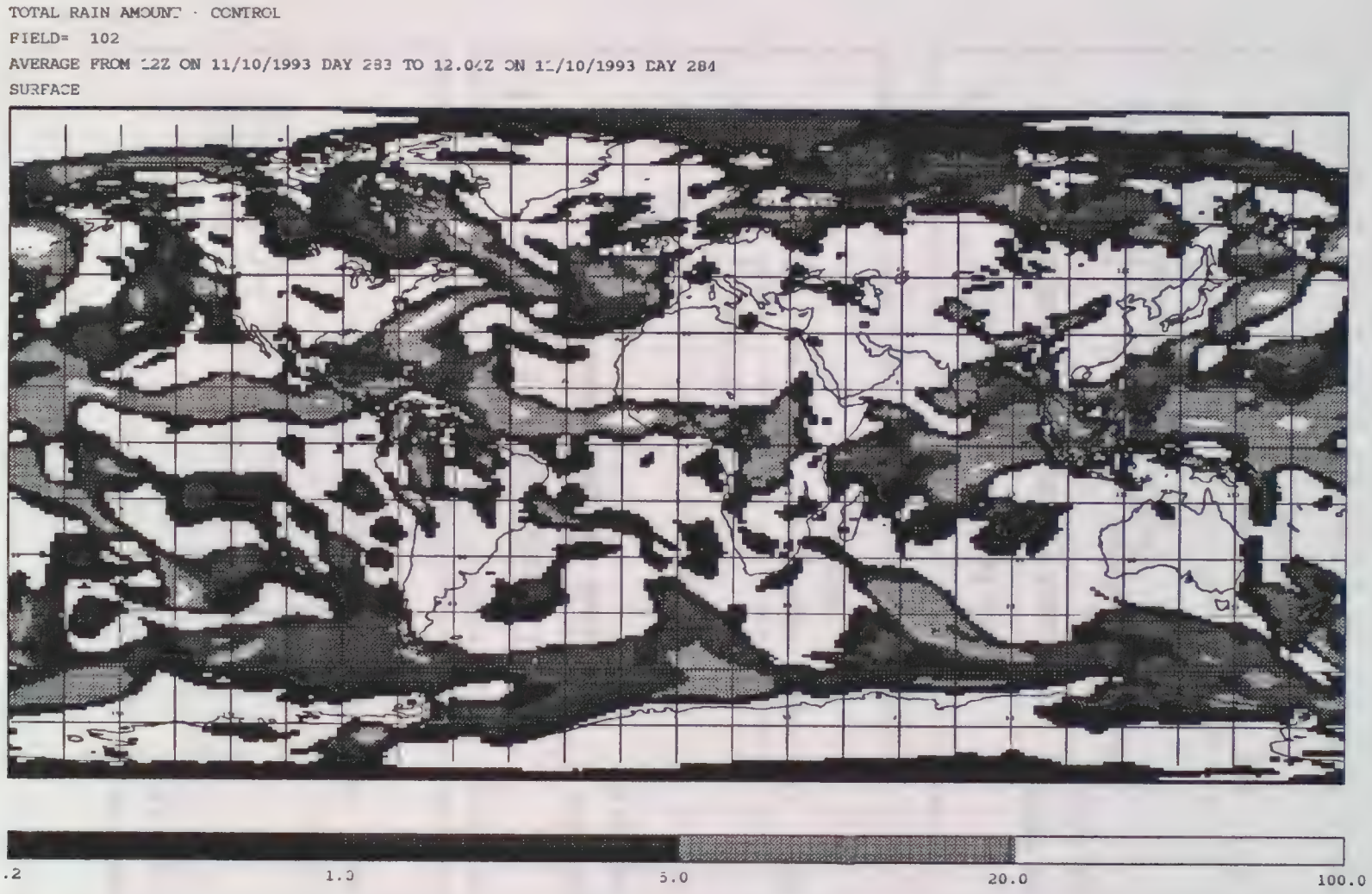


Figure 14 6 hour global precip accum (6-12z 11/10/93) from control run.

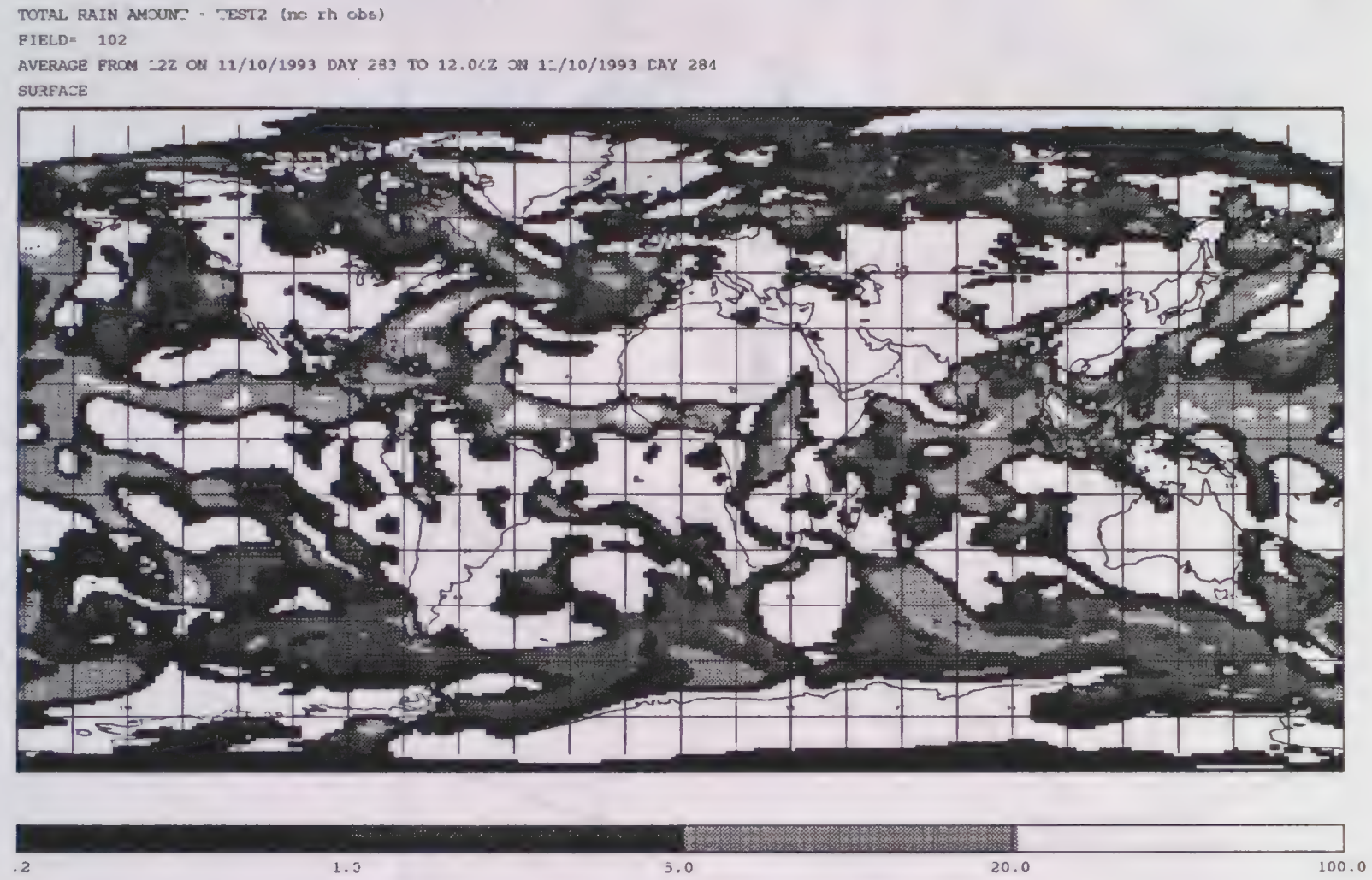


Figure 15 6 hour global precip accum (6-12z 11/10/93) from trial run.

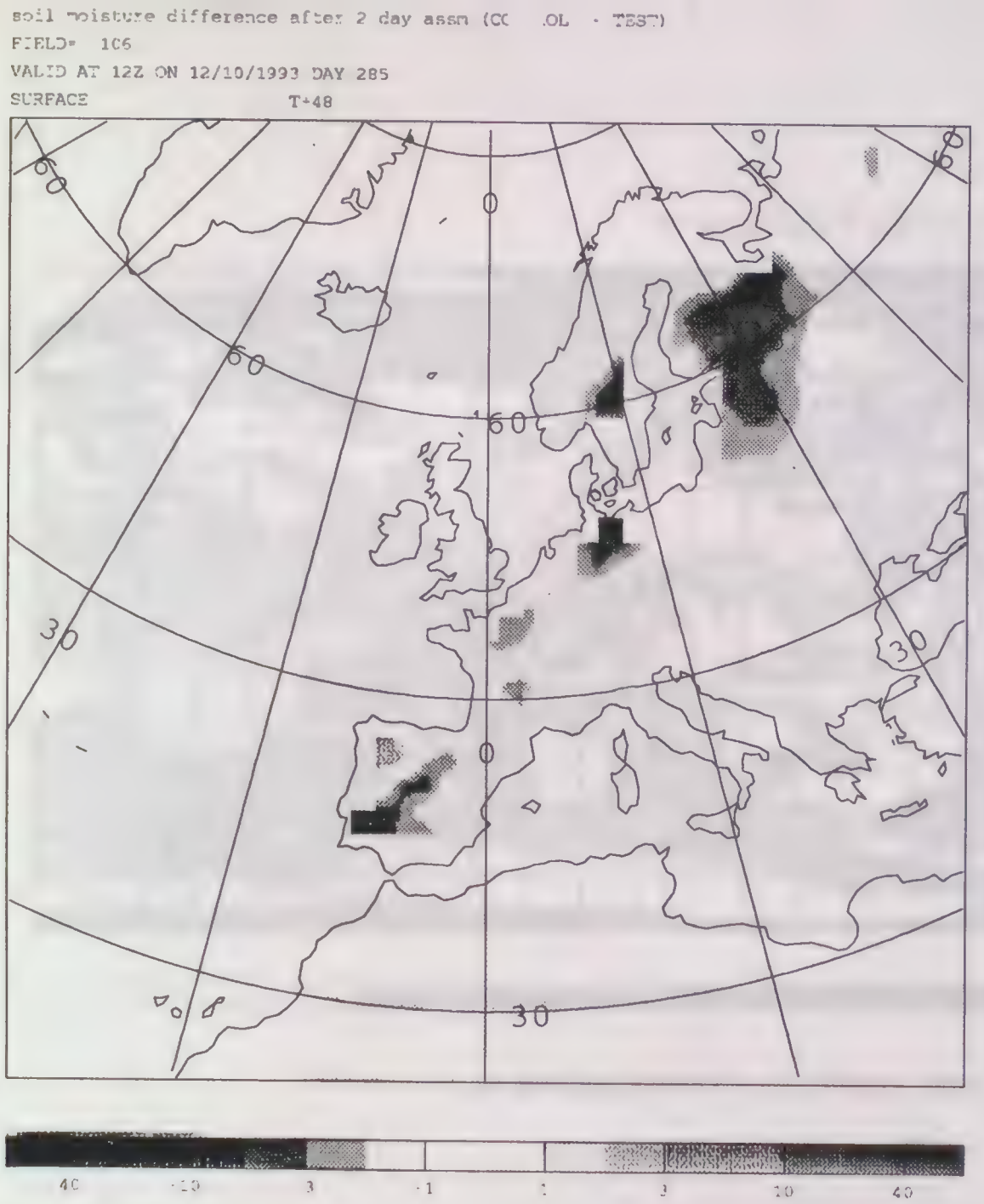


Figure 16 Soil moisture differences (control-trial) after 2 days assimilation: Oct 93 case

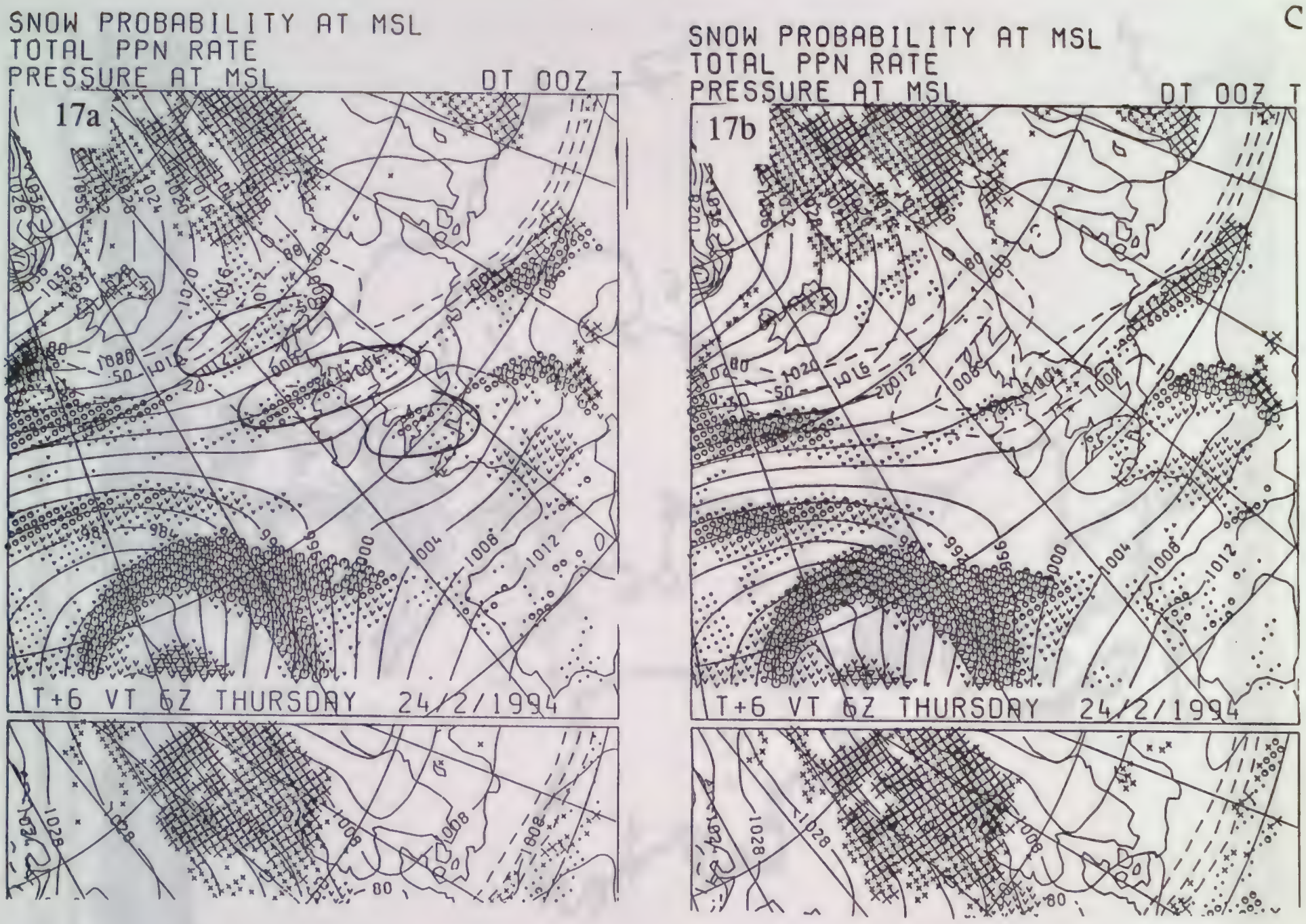


Figure 17 LAM T+6 forecast precip (a)trial and (b)control for 24th Feb 1994

Figure 18 Radar verification for 24th Feb 1994 forecasts.

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